Description

POSITION SENSING METHOD AND APPARATUS FOR A LINKAGE SYSTEM

Technical Field

[01] This invention relates to a position sensing method and apparatus for a linkage system and, more particularly, for sensing the position of a first linkage member relative to a second linkage member.

Background

[02] Known linkage systems, such as those using fluid cylinders to change linkage length and angular orientation, typically utilize controls wherein information relating to linkage length and/or velocity of linkage movement is required. The electrical aspects of control apparatus for such systems generally require the use of a variety of sensors, including, but not limited to, linkage position sensors, and may also utilize electro-hydraulic valves and/or an onboard electronic control module operable for executing a control strategy for linkage movement. Such control strategies often comprise a linkage position input that may be embodied, for instance, in positional and/or velocity information relating to one of the linkage members, such as a cylinder rod. Such positional and velocity information may be collected, for example, by a position sensor coupled to the cylinder rod.

[03] Reliable and accurate data collection from such sensors has been found to be largely dependent upon the ability to maintain the integrity of the sensors under adverse operating and environmental conditions, such as heat, cold, dust, dirt, and contact with rocks, debris, and other objects or factors that can damage the sensor and/or its path of communication with other elements of the control system. In order to reduce the potential for sensor damage resulting from such operating and environmental factors, one or more sensor components may be encased directly within a cylinder housing or body. However, internal

mounting of sensor componentry may subject the componentry to increased pressures or temperatures and may undesirably increase the deadlength of the cylinder in which it is embedded. In addition, such internal sensor systems may be inappropriate for use with linkage components having small internal dimensions.

[04] Moreover, the recent advance in position sensing technology, *e.g.*, accuracy, has produced a need to retrofit old or existing hydraulic cylinders and other linkage systems with such position sensing technology. For example, an earthmoving machine fitted with a Global Positioning System (GPS) may provide added benefits if retrofitted with an accurate, reliable, and robust position sensor assembly. However, many existing position sensor assemblies, such as internally oriented sensor systems, are often difficult or expensive to retrofit to existing cylinders since disassembly, replacement, or machining of significant cylinder or other linkage components may be required. Further, many existing position sensor assemblies require very particular mounting configurations relative to linkage systems, and the versatility of such assemblies may be limited by these mounting requirements.

[05] U.S. Patent No. 5,717,330 issued to Moreau *et al.* discloses a magnetostrictive linear displacement transducer that may be mounted internally to the piston of a hydraulic cylinder. Moreau discloses a transducer having transducer componentry mounted inside a hydraulic cylinder. In one embodiment, a magnet is mounted on a piston inside the hydraulic cylinder, and a coil is mounted on the exterior of the cylinder. Such a device incorporates one or more of the disadvantages described above. For example, the device provides limited adaptability since the cylinder must be formed of a non-ferromagnetic material in order for the device to function properly. Moreover, it should be appreciated that the coil of such a device, even though externally mounted relative to the cylinder, must be disposed very close to or in contact with the cylinder in order to produce the desired interaction between the externally mounted coil and the internally mounted magnet. Further, the disclosed

arrangement may limit or prevent the adaptability of the device to a cylinder lacking a flat or linear outer surface or a cylinder having external componentry disposed about its outer surface that would interfere with or prevent positioning the coil along and in contact with the cylinder.

[06] Other existing position sensor assemblies, such as cable extension transducers or "yo-yo sensors", may provide mounting flexibility but may be less accurate than desired when used in challenging environments. One example of a cable extension transducer includes a transducer housing that encloses a spring-loaded spool about which is wrapped a flexible stainless steel cable. The housing may be mounted to a fixed surface, and one end of the cable may be mounted to a movable object. As the object moves relative to the fixed surface, the spool rotates to release or retract the cable as necessary and the transducer produces an electrical signal that is proportional to the rotation of the spool and the extension or retraction distance of the cable. However, during certain conditions, such as high temperature and/or high-speed operations, the cable may stretch or the spool may not retract quick enough, thereby causing inaccuracies in the transducer's reading. Moreover, the cable or other components of the cable extension transducer may be susceptible to damage from environmental factors, such as debris or falling rock, for example.

[07] Accordingly, the present invention is directed to overcoming one or more of the problems set forth above.

Summary of the Invention

[08] According to one aspect of the invention, a position sensor assembly adapted to mount externally to a linkage system may comprise first and second sensor housing members and first and second sensor portions. The first sensor housing member may be adapted for external connection to the linkage system, may have a first sensor conduit therein, and may be configured and arranged to at least partially enclose the first and second sensor portions. The second sensor housing member may be slidably received within the first sensor

housing member and may have a second sensor conduit therein. The first sensor portion may be connected with the first sensor housing member, and the second sensor portion may be connected with the second sensor housing member. The position sensor assembly may be operable to register a position of the first sensor portion relative to the second sensor portion as a result of cooperation between the first and second sensor portions.

[09] According to another aspect of the invention, a linkage and sensor system may comprise a first linkage member and a second linkage member movably connected to the first linkage member. The system may further comprise a position sensor assembly externally connected to the first and second linkage members. The position sensor assembly may comprise first and second sensor housing members and first and second sensor portions. The first sensor housing member may be externally connected with one of the first and second linkage members, may have a first sensor conduit therein, and may be configured and arranged to at least partially enclose the first and second sensor portions. The second sensor housing member may be externally connected to the other of the first and second linkage members, may be slidably received within the first sensor housing member, and may have a second sensor conduit therein. The first sensor portion may be connected with the first sensor housing member, and the second sensor portion may be connected with the second sensor housing member. The position sensor assembly may be operable to register a position of the first linkage member relative to the second linkage member as a result of cooperation between the first and second sensor portions.

[10] According to a further aspect of the invention, a linkage and sensor system may comprise a first linkage member, a second linkage member movably connected to the first linkage member, and a self-aligning position sensor assembly connected with the first and second linkage members. The position sensor assembly may comprise a first sensor portion, a second sensor portion, a sensor housing member, and at least one self-aligning mounting member. The first sensor portion may be operatively connected to the first

linkage member, and the second sensor portion may be operatively connected to the second linkage member. The sensor housing member may at least partially enclose at least one of the first and second sensor portions. The at least one self-aligning mounting member may connect the sensor housing member externally to the first linkage member and may be operable to align the sensor housing member in a predetermined orientation relative to the first linkage member during assembly of the sensor housing member with the first linkage member. The position sensor assembly may be operable to register a position of the first linkage member relative to the second linkage member as a result of cooperation between the first and second sensor portions.

[11] According to yet another aspect of the invention, a method of determining the position of a first linkage member relative to a second linkage member is provided. The method may include adapting the first linkage member with a first sensor portion that is at least partially enclosed by a first sensor housing member. The method may also include adapting the second linkage member with a second sensor portion that is connected to a second sensor housing member and that is at least partially enclosed by the first sensor housing member. The first and second sensor portions and the first and second sensor housing members may be externally disposed relative to the first and second linkage members. In addition, the first sensor portion may be configured in a telescopically movable relationship relative to the second sensor portion. The method may further include moving the first linkage member relative to the second linkage member and causing the first sensor housing member to enclosingly and slidably receive the second sensor housing member. Thus, the position sensor assembly may be caused to register a position of the first linkage member relative to the second linkage member as a result of cooperation between the first and second sensor portions.

[12] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

Brief Description of the Drawings

[13] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate several exemplary embodiments of the invention and, together with the description, serve to explain the principles of the invention. In the drawings,

[14] **Fig. 1** is a perspective view of an embodiment of a linkage and sensor system including a linkage system and a position sensor assembly;

[15] **Fig. 2** is a cross-sectional view of the linkage and sensor system of **Fig. 1**;

[16] **Fig. 3A** is a partial perspective view of a sensor system including an alternative attachment arrangement and an alternative module housing member arrangement;

[17] **Fig. 3B** is a partial cutaway perspective view of a linkage and sensor system having an alternative attachment mechanism for the position sensor assembly;

[18] **Fig. 4** is an enlarged partial perspective view of the mounting arm and connecting pin of the linkage and sensor system shown in **Fig. 1**;

[19] **Fig. 5** is a cross-sectional view of an alternative embodiment of a linkage and sensor system;

[20] **Fig. 6** is an enlarged partial cross-sectional view of one end of the first housing member shown in **Fig. 2**; and

[21] **Fig. 7** is an enlarged partial cross-sectional view of one end of the second housing member shown in **Fig. 2**.

[22] Although the drawings represent several embodiments of the present invention, the drawings are not necessarily to scale, and certain features may be exaggerated in order to better illustrate and explain the present invention. The exemplifications set out herein illustrate exemplary embodiments of the invention and such exemplifications are not to be construed as limiting the scope of the invention in any manner.

Detailed Description

[23] Reference will now be made in detail to embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same or corresponding reference numbers will be used throughout the drawings to refer to the same or corresponding parts.

[24] **Fig. 1** shows an exemplary position sensor assembly **10** combined with an exemplary linkage system **14**, the combination forming an exemplary linkage and sensor system **15**. The position sensor assembly **10** may be externally connected to the linkage system **14** by one or more mounting members **16a, 16b** and/or mounting arm(s) **20**, each of which will be described in greater detail hereinbelow.

[25] The illustrated linkage system **14** includes a first linkage member, such as a fluid cylinder **18**, and a second linkage member, such as a piston and rod assembly **22** reciprocally disposed within the fluid cylinder **18**. It should be appreciated that the terms "first linkage member" and "second linkage member" are used herein for explanatory purposes and may be interchangeably applied to the piston and rod assembly **22**, the cylinder **18**, and/or various other components of a linkage system. Moreover, the linkage system **14** may, alternatively or in addition, comprise different components or linkage members, such as a frame, bucket, or other implements or components of an earthmoving machine, each of which may be referred to as a "first linkage member" or a "second linkage member."

[26] The cylinder **18** illustrated in **Fig. 1** includes fluid ports **26a, 26b** for the administration of pressurized fluid to one or more internal portions of the fluid cylinder **18**. One skilled in the art will appreciate that controlled administration of a pressurized fluid, such as hydraulic fluid, internally to the fluid cylinder **18** via one or more fluid ports **26a, 26b** causes extension and retraction of the piston and rod assembly **22** relative to the fluid cylinder **18**. One

or more mounting ends **30** may be provided at one or both ends of linkage system **14** to facilitate connection of the linkage system **14** to one or more additional linkage members (not shown), such as various implements or other components of earthmoving machines, compactors, or rams, for example. It should be appreciated that the cylinder **18** may be formed from ferrous materials, such as steel for example, or may be formed from non-ferrous materials if desired.

[27] The position sensor assembly **10** shown in **Fig. 1** includes a first housing member **48**, such as an outer sensor tube body, which may be configured and arranged to enclose various portions of the position sensor assembly **10** and to, therefore, protect such portions from potentially adverse operating and environmental conditions. The first housing member **48** may be operably connected to the cylinder **18** of the linkage system **14**. The position sensor assembly **10** may further include a second housing member **52** or sensor member, such as an inner sensor tube body. The second housing member **52** may be telescopically received within the first housing member **48** in one aspect and operably connected to a component **22** of the linkage system **14** in another aspect. In one exemplary embodiment, the housing members **48, 52** connect linkage members -- such as the cylinder **18** and the piston and rod assembly **22** -- to first and second sensor portions **56, 60** (**Fig. 2**), respectively. It should be appreciated that the terms "first sensor portion" and "second sensor portion" are used herein for explanatory purposes and may be interchangeably applied to various components of the position sensor assembly **10**, such as a pressure pipe/waveguide (**56**) and a magnet (**60**), as illustrated in **Fig. 2**.

[28] The sensor components of the position sensor assembly **10** may vary as conditions require or as desired by a user. For example, the sensor components may form a resistive type sensor, a capacitive type sensor, a magnetostrictive type sensor, an inductive type sensor, or some other type sensor known in the art. The position sensor assembly **10** shown in **Fig. 2** comprises a magnetostrictive type sensor **64** for determining the position of the piston and rod

assembly **22** relative to the fluid cylinder **18**. The sensor **64** includes a first sensor portion **56** operably connected with at least one component of the linkage system **14** and extending axially within a passage or conduit **76** of the first housing member **48**. The first sensor portion **56** may also be telescopically received within a passage or conduit **80** of the second housing member **52**. Such an arrangement allows the first sensor portion **56** to be embedded deeply within the position sensor assembly **10** for greater protection of the first sensor portion **56** from external conditions.

[29] The first sensor portion **56** illustrated in **Fig. 2** contains a magnetostrictive element or waveguide (not shown) that extends through the first sensor portion **56** and interacts with an interactive second sensor portion **60**, such as a magnet. The second sensor portion **60**, which may be connected with the second housing member **52**, is configured and arranged to be movable relative to the first sensor portion **56**. For example, as illustrated in **Figs. 2 and 7**, the second sensor portion **60** may have an annular or semi-annular configuration and may be movably arranged in a telescopic configuration relative to the first sensor portion **56**.

[30] Referring again to the embodiment shown in **Fig. 2**, the first sensor portion **56** is electrically connected to the sensor **64**. The sensor **64** further comprises a current generator (not shown) operable for generating current pulses, which are sent through the first sensor portion **56**. The second sensor portion **60** encircles the first sensor portion **56** and provides a magnetic field that interacts with the current pulse. This interaction causes within the first sensor portion **56** a torsional pulse that is transmitted back to the sensor **64** as a torsional strain wave having a time period. The torsional strain wave is sensed by a mode converter or other conventional sensor element (not shown) in the sensor **64**, which generates an output wave signal in response to the torsional strain wave. The output wave signal is then communicated to a sensor electronics module **68**, which compares the time of receipt of the output wave signal to the time of launch of the initial

current pulse to determine the position of the second sensor portion **60** relative to the first sensor portion **56** and to output a position signal representative thereof. The position signal is transferred or communicated to a control center, such as an electronic control module (ECM) (not shown), for example, through the connector **72** and associated wires. As shown in **Fig. 2**, the sensor electronics module **68** may be enclosed within a module housing member **44**. In an alternative embodiment, the sensor electronics module **68** may be configured and arranged in a different location or orientation, such as being disposed at a location distant from the sensor **64**.

[31] The position sensor assembly **10** shown in **Figs. 1** and **2** includes a module housing member **44** disposed at one end of the position sensor assembly **10**. The module housing member **44** may provide an internal cavity for receipt and protection of the sensor electronics module **68**. The module housing member **44** may have a rectangular cross-section (as illustrated in **Fig. 1**) or may, alternatively, have a circular or otherwise non-rectangular cross-section as desired. For example, **Figs. 3A and 8** show alternative embodiments having a module housing member **44** with a generally circular cross section. Such housing members **44** may be formed, for example, from steel tubing or from steel round bar material. It should be appreciated that the module housing member **44** may comprise a flange portion having a threaded area thereon. The flange portion may be welded or otherwise connected to the first housing member **48**, and the sensor module **68** may be screwed into the flange portion via complimentary threads disposed on the sensor module **48**.

[32] Referring to **Figs. 2, 3A, and 8**, the sensor module **68** may be press-fit inside the internal cavity of the module housing member **44** or may be secured inside the module housing member **44** by a set screw **84** (shown in **Figs. 1 and 8**), by complimentary threads disposed on the sensor module **68** and the module housing member **44**, or by one or more additional or alternative attachment mechanisms known in the art. The module housing member **44** may

include an opening **88** for accessing or removing the sensor module **68** as desired. A removable plug member **92** may be applied to the module housing member **44** for selectively closing the opening **88**. The plug member **92** may be attached to the module housing member **44**, for example, by complimentary threading formed on the plug member **92** and the module housing member **44** or by a press fit configuration therebetween, and a gasket **96** may be provided between the plug member **92** and the module housing member **44** to seal the connection therebetween.

[33] It should be appreciated from the foregoing discussion and the referenced figures that the sensor module **68** may be securely encased within the position sensor assembly **10** (*e.g.*, within module housing member **44**) to significantly reduce the likelihood of damage to the sensor module **68** and/or compromise of the sensor function during operation of the position sensor assembly **10**. It should further be appreciated that the disclosed embodiments may provide such protection for the sensor module **68** while also allowing convenient access to the sensor module **68**.

[34] An orifice **100** may be provided in the wall of the module housing member **44** for passage of the connector wiring and/or the connector **72** therethrough during assembly or maintenance operations. It should be appreciated that the orifice may, alternatively or additionally, be provided in the plug member **92**. In the embodiment of **Figs. 1** and **2**, a mounting plate **104** and a mounting bracket **108** are attached to the module housing member **44** for securing the connector **72** and its associated wiring to the module housing member **44**. A connector cover **112** for protecting the connector **72** and its associated wiring from external factors may also be attached to the module housing member **44** by one or more screws or bolts **110**, for example.

[35] In a first alternative embodiment (**Fig. 8**), the connector **72** may be attached to the exterior of the housing member **48**, such as underneath the

housing member **48** between the housing member **48** and the linkage system **14**. In addition, a connector cover **112** may be provided to cover the connector **72** and its associated wiring and to provide additional protection thereto. Moreover, in such an embodiment, an orifice **144e** may be provided within the mounting member **16c** for passage of the connector wiring and/or the connector **72** therethrough.

[36] In a second alternative embodiment (**Fig. 3A**), the connector **72** may be at least partially encased within the module housing member **44** to provide additional protection for the connector **72** from external factors. For example, a mounting bracket **72a** connected to the connector **72** may be connected to an interior portion of the module housing member **44**, such as with a set screw **84**, for securing the connector **72** at least partially inside the module housing member **48**. Further, an orifice **98a** may be provided within the plug member **92** (and/or within the housing member **44**) for passage of a mating connector (not shown) therethrough to be connected with the connector **72**. Alternatively, the connector **72** may be at least partially disposed and arranged inside the orifice **98a** to allow connection of an external mating connector (not shown) thereto. Moreover, a cap member **98b** may be provided inside the orifice **98a** for at least partially closing the orifice **98a**.

[37] The module housing member **44** may further include a bore **114** for receipt of the first housing member **48**. The first housing member **48** may be secured to the module housing member, for example, by a press-fit configuration with the bore **114**, by complimentary threads disposed on the first housing member **48** and the bore **114**, by a welded connection, by a flange-type connection, or by a variety of additional or alternative mechanisms known in the art. The module housing member **44** may also include a sensor port **116** formed through a wall of the module housing member **44** to allow the first sensor portion **56** to extend through the wall of the module housing member **44** and into a left end (as viewed from the perspective shown in **Fig. 2**) of the first housing member

48. As mentioned above, the first housing member **48** may generally define or form an internal passage or conduit **76**, through which the first sensor portion **56** may extend toward a right end (as viewed from the perspective shown in **Fig. 2**) of the first housing member **48**.

[38] Referring to **Figs. 2 and 6** and referencing the right end of the first housing member **48**, an opening **118** may be formed in the first housing member **48** for receipt of the second housing member **52**. The conduit **76** and the opening **118** each may have a generally circular cross-section, as illustrated in **Fig. 1**, or a generally noncircular cross-section, such as, for example, a generally rectangular or triangular cross-section, as desired.

[39] **Fig. 6** shows a guide member **120**, which may be attached to the first housing member **48** at its opening **118**, for example, and which may be configured and arranged to ensure or at least facilitate a snug and slidable interface between the first housing member **48** and the second housing member **52**. A contact portion **120a** of the guide member **120** may be formed from acetal, polyoxymethylene, or some other plastic or like material so that the guide member **120** has a high wear resistance and so that little or no lubrication is required for smooth interaction between the guide member **120** and the second housing member **52** during operation of the position sensor assembly **10**. Guide member **120** may further comprise a flexible member or wiper element **120b** formed, for example, from a rubber material and having an internal diameter slightly smaller than the outer diameter of the second housing member **52**. The flexible member **120b** may be designed to deform as necessary during operation to ensure a snug interface between the two housing members **48, 52** and may be configured to perform a wiper function over the outer surface of the second housing member **52** to prevent, limit, or at least inhibit moisture, dirt, or other factors from entering the second housing member **52** during operation. The guide member **120** may be attached to the first housing member **48** by a press-fit configuration (as shown in **Fig. 6**), by complimentary threads disposed on the

guide member **120** and the first housing member **48**, or by other attachment mechanisms known in the art.

[40] The second housing member **52** may be slidably received within the opening **118** of the first housing member **48**. Moreover, as illustrated in **Figs. 2 and 7**, the second housing member **52** may define or form an internal passage or conduit **80**. The second housing member **52** may further have an opening **124** at one end thereof for slidably receiving the first sensor portion **56** into the conduit **80**. It should be appreciated that the conduit **80** may have either a generally circular cross-section, as illustrated in **Fig. 1**, or a generally noncircular cross-section, such as a generally rectangular or triangular cross-section, as desired.

[41] Referring again to **Figs. 2 and 7**, a guide member **128** may be attached to the second housing member **52**, for example at the opening **124**, and may be configured and arranged to ensure or at least facilitate a snug and slidable interface between the second housing member **52** and the first housing member **48**. The guide member **128** may be attached to the second housing member **52** by a press-fit configuration (as shown in **Fig. 7**), by complimentary threads disposed on the guide member **128** and the second housing member **52**, or by other attachment mechanisms known in the art. At least a portion **128a** of the guide member **128** may be formed from acetal, polyoxymethylene, or some other plastic or like material so that the guide member **128** has a high wear resistance and so that little or no lubrication is required for smooth interaction between the guide member **128** and the first housing member **48** during operation of the position sensor assembly **10**.

[42] As illustrated in **Fig. 2**, the first sensor portion **56** may be at least partially arranged within and enclosed by the conduit **76** of the first housing member **48**. Moreover, the first sensor portion **56** may be configured to move with the first housing member **48**. For example, the first sensor portion **56** shown

in **Fig. 2** is secured to or integrally formed with the sensor module **68**. The sensor module **68** is secured to the module housing member **44**, which is secured to the first housing member **48**. Thus, the first sensor portion **56** of **Fig. 2** is generally suspended within and configured to move with the first housing member **48**. It should be appreciated that, in an alternative embodiment, the first sensor portion **56** may be attached directly to the module housing member **44** or to the first housing member **48**.

[43] Referring to **Fig. 2**, the first sensor portion **56** may be slidably received within the conduit **80** of the second housing member **52** through opening **124**. The first sensor portion **56** may include a guide member **130** (**Fig. 6**) disposed within the conduit **80** between the first sensor portion **56** and the second housing member **52**. The guide member **130** may be configured and arranged about the first sensor portion **56** to prevent, limit, or at least inhibit contact -- or the transmission of force between -- the first sensor portion **56** and the second housing member **52**. For example, the guide member **130** may have a larger outer diameter than the first sensor portion **56**. In addition or alternatively, the member **130** may function as a stopper to prevent or inhibit the inadvertent removal of the first sensor portion **56** from within the conduit **80** during operation. For example, the outer diameter of the member **130** may be sized larger than the inner diameter of the opening **124**. The member **130** may be affixed to, or integrally formed with, the first sensor portion **56** by a press-fit configuration, by a threaded bolt **136**, which may be screwed into a threaded opening (not shown) within the first sensor portion **56**, or by some other attachment mechanism known in the art. It should be appreciated that the member **130** and the bolt **136** may be integrally formed into a single unit. The guide member **130** may be formed from such materials as plastic, rubber, or other suitable materials known in the art.

[44] As illustrated in **Figs. 2 and 7**, a sensor portion **60**, such as a magnet, may be attached to the second housing member **52** and may be at least

partially enclosed by the second housing member **52** or the guide member **128**. The second sensor portion **60** may be attached to the guide member **128**, which is secured to the second housing member **52**. Alternatively, the second sensor portion **60** may be directly attached to the second housing member **52**. Thus, the second sensor portion **60** may be configured to move with the second housing member **52** so that relative movement between the second housing member **52** and the first housing member **48** causes relative movement between the second sensor portion **60** and the first sensor portion **56**. The second sensor portion **60** may be attached to the guide member **128** in a variety of ways, such as by a press-fit configuration, by mating threads formed on the second sensor portion **60** and the guide member **128**, or by alternative or additional attachment mechanisms known in the art. For example, the embodiment shown in **Fig. 7** includes a press ring **132**, which is affixed to the guide member **128** by a press-fit configuration to ensure that the second sensor portion **60** is secured within the guide member **128**.

[45] Referring to **Fig. 1**, the position sensor assembly **10** may be attached to the linkage system **14** by one or more mounting members **16a, 16b** and/or one or more mounting arm(s) **20**. For example, the first housing member **48** may be attached externally to one of the linkage system components, such as the cylinder **18**, by a mounting member **16a, 16b** having a contoured mounting surface **140**. As illustrated in **Figs. 1** and **2**, multiple mounting members **16a, 16b** may be used as desired. It should be appreciated that, in an alternative embodiment, the second housing member **52** may be attached to one of the linkage system components, such as the cylinder **18**, by a mounting member **16a, 16b**.

[46] As shown in **Fig. 1**, the contoured mounting surface **140** of at least one of the mounting members **16a, 16b** may be configured to self-align with one of the components of the linkage system **14**, such as the outer surface of the cylinder **18**, to facilitate connection of the position sensor assembly **10** in a

predetermined orientation relative to the linkage system **14**. For example, the contoured mounting surface **140** may provide a curved area that generally mates with the outer circumferential curvature of the wall of the cylinder **18**. Thus, upon application of the contoured mounting surface **140** to the cylinder **18**, the mounting member **16a, 16b** -- and, therefore, the position sensor assembly **10** -- may be quickly and automatically aligned with the cylinder **18** as desired. Moreover, as shown in **Fig. 1**, the contoured mounting surface **140** may be configured to facilitate attachment of the first housing member **48** to the cylinder **18** in a generally parallel and spaced apart orientation. Such a self-aligning mounting member **16a, 16b** may simplify mounting of the position sensor assembly **10** to the linkage system **14**, especially during on-site assembly operations -- *i.e.,* when precision alignment tools may not be accessible. In order to ensure an accurate and tight alignment of the position sensor assembly **10** with the cylinder **18**, the curvature of the contoured mounting surface **140** may have a slightly smaller radius of curvature than that of the cylinder **18**.

[47] As illustrated in **Fig. 1**, mounting members **16a, 16b** may comprise top and bottom mounting portions **144a, 144b**, which may be secured together by one or more screws or bolts **148** or by other attachment mechanisms known in the art. The top and bottom mounting portions **144a, 144b** may each include a generally semicircular contour for mating with a generally cylindrical housing member **48**. As indicated in **Fig. 3A**, alternative configurations for a mounting member **16c** are also envisioned. For example, a mounting member **16c** may include front and rear mounting portions **144c, 144d**. The mounting portions **144c, 144d** may include notched or otherwise contoured areas **146, 147** for complimentary engagement and for simplified and secured alignment of the mounting portions **144c, 144d**. The front and rear mounting portions **144c, 144d** may be secured together by one or more screws or bolts **148** or by other attachment mechanisms known in the art. With the embodiments described above, a mounted but untightened housing member **48** may be rotated relative to the mounting members **16a, 16b, 16c** until the position sensor assembly **10** is in a

desired orientation relative to linkage system **14**. Bushings **153** or grommets, such as rubber grommets, may be provided between the mounting portions **144a, 144b, 144c, 144d** and the secured position sensor componentry to prevent or at least inhibit vibration of the position sensor componentry during operation and/or to ensure a tight fit between the mounting portions **144a, 144b, 144c, 144d** and the secured position sensor componentry.

[48] Each mounting member **16a, 16b** may be secured to the linkage system **14** via, for example, a welded connection (**Fig. 1**) or a strap **150** (**Fig. 3B**), which may be secured tightly around the mounting member **16a, 16b** and the linkage system component **18** to which the mounting member **16a, 16b** is attached. When a strap **150** is used, the upper mounting portion **144a** may further comprise a contoured portion **152** defining a channel for receipt of the strap **150**. Such straps **150** may be formed, for example, from sheet metal and may be secured and tightened, for example, with a conventional nut and bolt configuration generally referenced as **151** in **Fig. 3B**.

[49] Referring to **Figs. 2 and 4**, a mounting arm **20** may also be used to attach one of the position sensor assembly components to one of the linkage system components. For example, with reference to **Fig. 4**, an end **20a** of the mounting arm **20** may be movably attached to an end of the second housing member **52**. A pin **156** may be inserted through holes **160** in a first end **20a** of the mounting arm **20** and through holes **160** in an end of the second housing member **52** so that the mounting arm **20** is rotatably connected to the second housing member **52**. In addition, notches **164** may be formed in the second housing member **52** to allow pivotal movement of the mounting arm **20** relative to the second housing member **52**. In alternative embodiments, the holes **160** may be elongated slots. For example, the holes **160** in the second housing member **52** may be elongated in a direction transverse to the length of the second housing member **52** to allow limited transverse movement of the second housing member **52** relative to the mounting arm **20**.

[50] Referring to **Fig. 2**, a second end **20b** of the mounting arm **20** may be attached to one of the linkage system components, such as the piston and rod assembly **22** or a mounting end **30**, so that the mounting arm **20** operably connects the position sensor assembly **10** to the linkage system **14**. The attachment mechanism between the mounting arm **20** and the linkage system **14** may comprise, for example, a welded connection (as shown in **Fig. 2**), threads disposed on the mounting arm **20** that engage complimentary threads disposed on the piston and rod assembly **22**, or various other attachment mechanisms known in the art.

[51] As shown in **Fig. 4**, the interior of the second housing member **52** may be sealed off from the environment on at least one end, for example with a cap member **166** disposed inside the second housing member **52**, to further protect the sensor componentry from external factors. The cap member **166** may be connected to, or integrally formed with, the second housing member **52** with an adhesive, a welded connection, a press-fit connection, or with any of a variety of connection mechanisms known in the art.

[52] Referring to **Fig. 1**, during an assembly of the position sensor assembly **10** with the linkage system **14**, the first housing member **48** may be secured to the linkage system **14**, for example to the cylinder **18**, by one or more mounting members **16a, 16b**. The second housing member **52** may then be arranged at a desired location relative to linkage system **14** and attached to the linkage system **14** via the mounting arm **20**. For example, as shown in **Fig. 1**, the mounting arm **20** may be attached between the second housing member **52** and the piston and rod assembly **22**. If required, the mounting arm **20** may be shortened or rotated relative to the second housing member **52** during the assembly operation in order to ensure proper alignment of the second housing member **52** relative to the first housing member **48** and the linkage system **14**.

[53] It should be appreciated that the position sensor assembly **10** may be attached to the linkage system **14** by alternative or additional attachment mechanisms. For example, as illustrated in **Fig. 5**, one of the position sensor assembly components, such as the module housing member **44b**, may be connected directly to a mounting end **30**. The module housing member **44b** may comprise an external mounting extension **168** that is received within a bore **172** formed in the mounting end **30**. The extension **168** and the bore **172** may be provided with complimentary threads for securing the extension **168** to the bore **172**. Similarly, the extension arm **20** may be provided with an extension **176** for receipt within a bore **180** of a mounting end **30**. It should be appreciated that the housing member **44b** may, alternatively or in addition, be strapped or welded directly to the mounting end **30** or attached to the mounting end **30** by other attachment mechanisms described herein or known in the art.

[54] The module housing member **44, 44b**, the first housing member **48**, the second housing member **52**, the guide member **120**, the removable plug member **92**, and the mounting arm **20** may be formed from various materials known in the art such as steel or plastic, for example, and may be forged, cast, molded, or formed in any of a variety of ways known in the art.

Industrial Applicability

[55] In operation, and with specific reference to the embodiment shown in **Figs. 1 and 2**, pressurized fluid may be applied to or removed from internal portions of the fluid cylinder **18** via ports **26a, 26b**, thereby causing extension or retraction of the piston and rod assembly **22** within cylinder **18**. Such extension or retraction will cause corresponding movement of the second sensor portion **60** (**Fig. 2**) (via the second housing member **52**) relative to the first sensor portion **56** (via the first housing member **48**). As described above, interaction between the sensor components **60, 56** allows the position sensor assembly to electronically register a position of the second sensor portion **60** relative to the first sensor portion **56**. Moreover, the registered position ultimately represents

the position of the piston and rod assembly **22** relative to the cylinder **18** since the second sensor portion **60** moves with the piston and rod assembly **22** and the first sensor portion **56** moves with the cylinder **18**.

[56] The position sensor assembly **10** described in the foregoing paragraphs provides a robust device that is externally mountable to a linkage **14** system for determining the position of a first linkage member relative to a second linkage member. The position sensor assembly **10** may be configured and arranged to enclose and protect various sensor components from external conditions, such as dirt and debris, and may therefore be used in a variety of otherwise prohibitive conditions. For example, the disclosed position sensor assembly **10** may be mounted directly to earthmoving machines and used during excavating operations.

[57] The disclosed position sensor assembly **10** may be adaptable to many different configurations and types of linkage systems **14**. For example, because the sensor portions **56, 60** of the position sensor assembly **10** may each be externally mountable relative to a linkage system **14**, the disclosed assembly **10** may be used with ferrous or non-ferrous hydraulic cylinders **18**. In addition, the position sensor assembly **10** may be mounted in a variety of orientations relative to a linkage system **10**. For example, the assembly **10** may be mounted in a spaced-apart relationship relative to a linkage system **14** so that close proximity of the sensor portions **56, 60** relative to the linkage members is not required. Further, the position sensor assembly **10** may be applied to new linkage systems **14**, or the assembly **10** may be applied to existing/older linkage systems **14** that have less accurate or no position sensing capability.

[58] Moreover, the disclosed position sensor assembly **10** may provide a self-aligning mounting feature to facilitate accurate and efficient mounting and alignment of the assembly **10** to a linkage system **14**. Such self-alignment may prevent or limit alignment problems in the field, where access to mounting or alignment tools may be limited.

[59] From the foregoing it will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit or scope of the invention. Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and figures and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims and their equivalents. Accordingly, the invention is not limited except as by the appended claims.